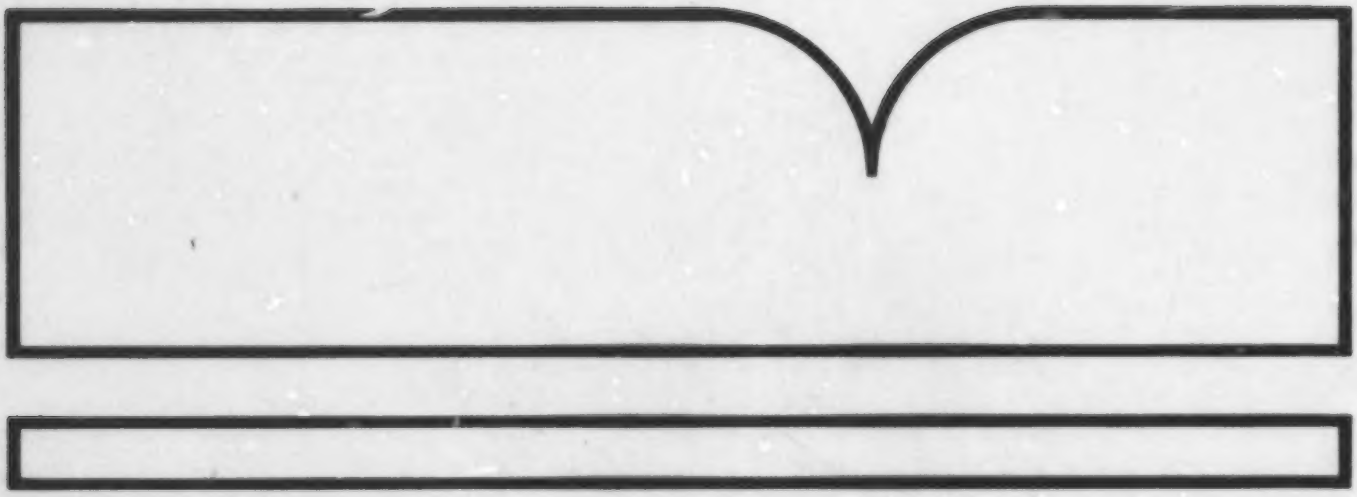
PB82-132440

Evaluating Costs and Benefits of Alternative Disinfectants

(U.S.) Municipal Environmental Research Lab.
Cincinnati, OH

1981



U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. REC
EPA-600/J-81-480	Journal Article	PB82-132440

4. TITLE AND SUBTITLE	5. REPORT DATE
Evaluating Costs and Benefits of Alternative Disinfectants	November 1981
	6. PERFORMING ORGANIZATION CODE 2337071
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Robert M. Clark	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Drinking Water Research Division, MERL, U.S.EPA 26 West St. Clair St. Cincinnati, Ohio 45268	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Drinking Water Research Division, MERL, U.S.EPA 26 West St. Clair St. Cincinnati, Ohio 45268	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Appeared in the Journal of the American Water Works Association (Vol. 73, No. 2, Feb. 1981)

16. ABSTRACT

Environmental Protection Agency regulation of the maximum contaminant level for total trihalomethanes, slong with the discovery that THMS are formed during the disinfection process, has led to increased scrutiny of disenfection practices. An analysis of the cost-benefit ratios of chlorination and other methods of disinfection concludes that the benefits associated with any type of disinfection far outweigh the costs.

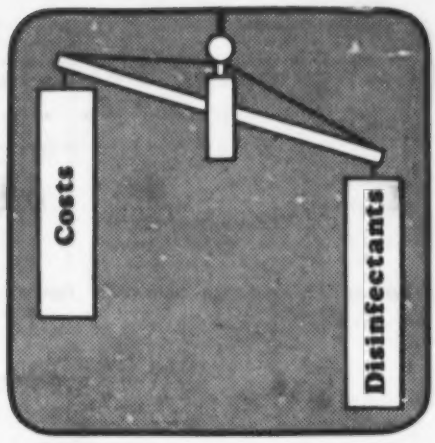
17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Benefit-Cost Analysis; Economic Analysis; Public Health; Water Supply; Water Treatment; Water Quality		

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
	20. SECURITY CLASS (This page)	22. PRICE

EPA-600/J-81-480
Journal Article



Evaluating costs and benefits of alternative disinfectants

Robert M. Clark

Environmental Protection Agency regulation of the maximum contaminant level for total trihalomethanes, along with the discovery that THMs are formed during the disinfection process, has led to increased scrutiny of disinfection practices. An analysis of the cost–benefit ratios of chlorination and other methods of disinfection concludes that the benefits associated with any type of disinfection far outweigh the costs.

On Nov. 29, 1979, the US Environmental Protection Agency (EPA) issued an amendment to the National Interim Primary Drinking Water Regulations that established a maximum contaminant level (MCL) of 0.10 mg/L for total trihalomethanes in drinking water.[1] Although the trihalomethane regulation contains a target MCL, EPA's intention is to allow utilities to determine specific treatment strategies, with the approval of the primary agency.

Three approaches are generally agreed on for controlling trihalomethanes: treatment for removal of total trihalomethanes (TTHMs) after formation; treatment for the removal of THM precursors; and the use of disinfectants other than free chlorine.[2] This paper addresses the third approach and will attempt to examine some of the costs and benefits associated with the disinfection process.

The discovery that chloroform was being produced in the chlorine disinfection process intensified interest in disinfection practices in general. Questions have been raised regarding the cost effectiveness of chlorination versus other disinfection alternatives. This controversy raises the possibility that disinfection may be challenged as a public health practice. In the author's opinion such a challenge is unjustified. To establish that disinfection has been a generally successful public health practice this paper presents historically documented costs and benefits associated with chlorination, alone and in combination with filtration. Other topics discussed include general cost characteristics of chlorination and alternative methods of disinfection; a comparison of costs among disinfectants at presumed equivalent dosages; and a comparison of energy utilization among alternative disinfection processes. The costs and benefits associated with the alternative disinfectants are compared on a common basis.

Disinfection costs and benefits

Disinfection is one of the most cost-effective preventive practices in the field of public health, especially in combination with filtration of surface waters. This statement is supported by examination of disinfection and filtration in terms of a cost-benefit analysis. The following analysis is based on the records of the Cincinnati Water Works and the Hamilton County (Ohio) Health Department.[3]

Historical costs and benefits. At the turn of the century, Cincinnati's sole source of supply was the Ohio River. After raw river water had been pumped to a reservoir and the mud had settled out, the city's distribution mains were supplied directly from this reservoir. Tap water was so full of foreign matter and bacteria that it posed the threat of an epidemic.

In 1907 Cincinnati's first treatment plant using settling and coagulation basins and rapid sand filters went into operation. Since 1915 chlorine has been used primarily for bacterial control. Figure 1 shows the incidence rates of typhoid per hundred thousand persons from 1905 to 1927, both before and after filtration and chlorination began. From the vertical lines indicating the introduction of filtration and chlorination it is obvious that the number of typhoid cases declined markedly after the introduction of each practice. Figure 2 shows the typhoid death rate per hundred thousand persons for the same time period. Again, lower death rates coincide dramatically with the introduction of each new technology.

To measure these effects the costs and benefits of these technological additions were calculated. Filtration and chlorination costs were obtained from Cincinnati Water Works records.[4] Benefits were calculated as the decrease in costs of death and sickness due to the introduction of each technology.[5]

Differential death and incidence rates were calculated for the various phases of treatment installation. The values were multiplied by the cost of lost income

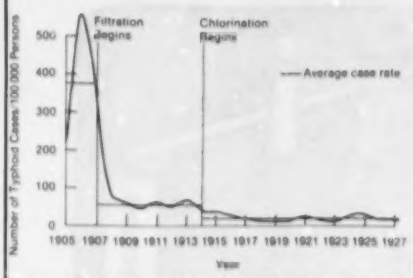


Figure 1. Number of typhoid cases from 1905 to 1927

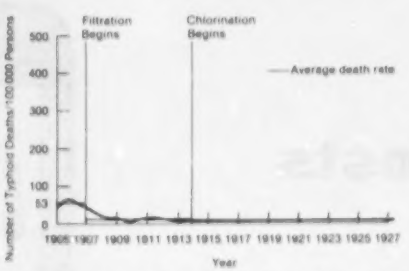


Figure 2. Number of typhoid deaths from 1905 to 1927

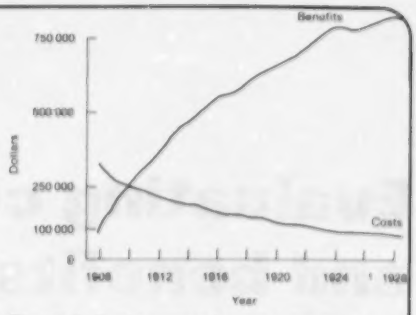


Figure 3. Costs versus benefits of filtration

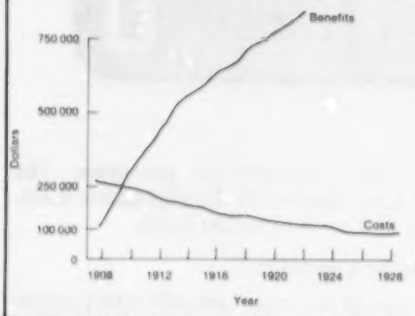


Figure 4. Costs versus benefits of chlorination and filtration

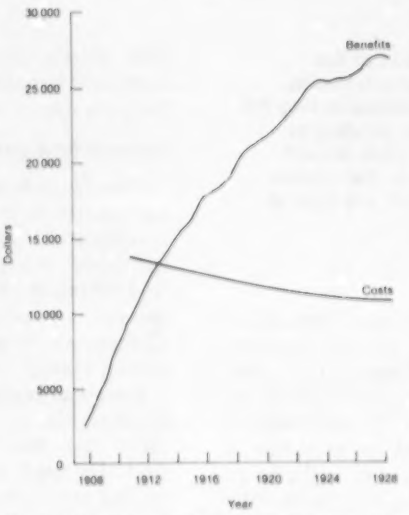


Figure 5. Costs versus benefits of chlorination
An 80 percent reduction of benefits is depicted.

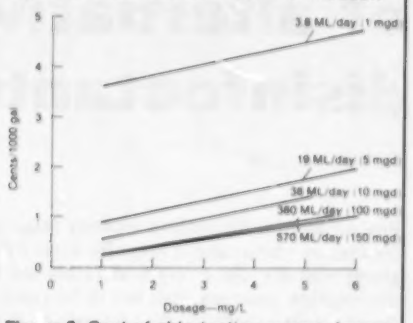


Figure 6. Cost of chlorination versus dosage without contact chambers for several water treatment plants

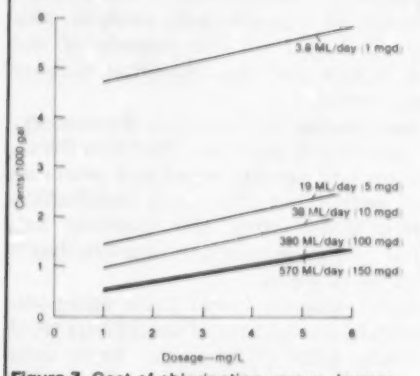


Figure 7. Cost of chlorination versus dosage with contact chambers for several water treatment plants

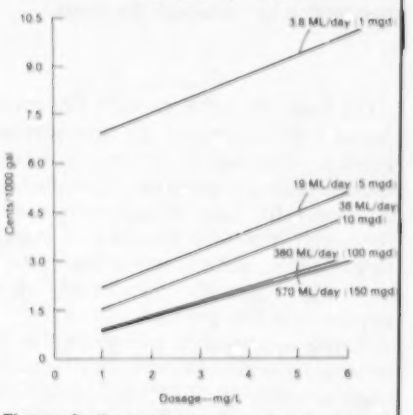


Figure 8. Cost of chlorine dioxide versus dosage with contact chambers for several water treatment plants

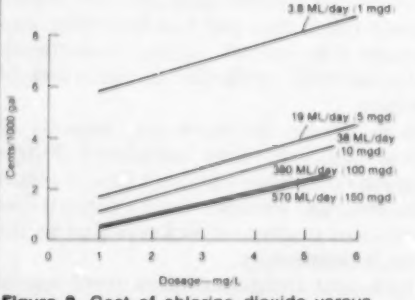


Figure 9. Cost of chlorine dioxide versus dosage without contact chambers for several water treatment plants

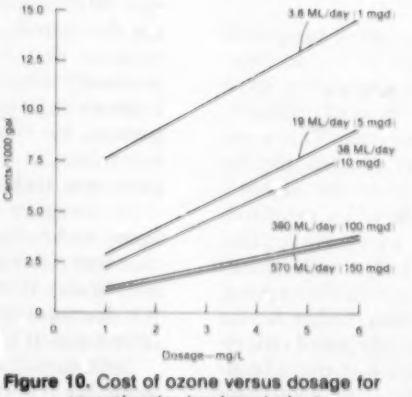


Figure 10. Cost of ozone versus dosage for several water treatment plants

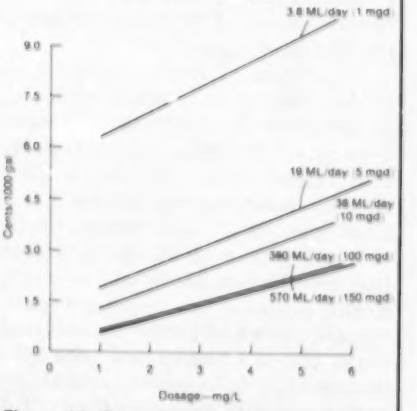


Figure 11. Cost of ammonia versus dosage without contact chambers for several water treatment plants

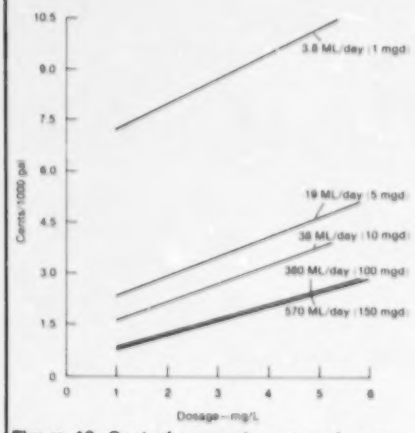


Figure 12. Cost of ammonia versus dosage with contact chambers for several water treatment plants

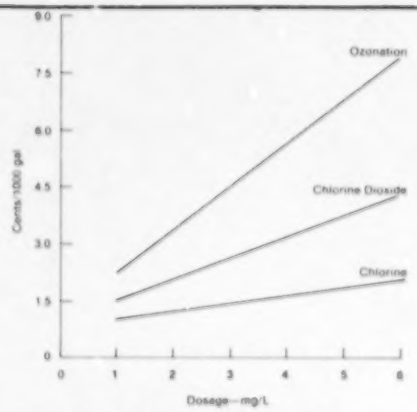


Figure 13. Total production costs versus dosage for chlorine, chlorine dioxide, and ozone at 38 ML/d (10 mgd)

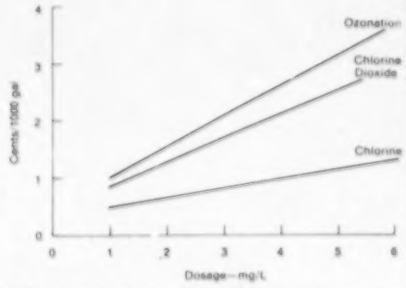


Figure 14. Total production costs versus dosage for chlorine, chlorine dioxide, and ozone at 380 ML/d (100 mgd)

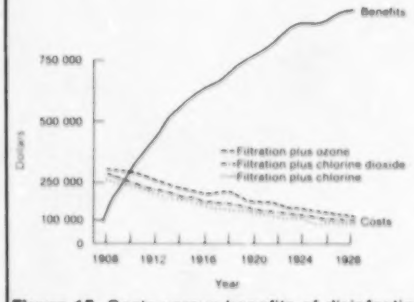


Figure 15. Costs versus benefits of disinfection and filtration

TABLE 1
Cost assumptions used

Parameters	Costing Factors
Energy	$0.04/kWh
Labor	$10.00/h
Producers price index (1980)	243.0
Engineering News Record index (1980)	325.0
Interest rate	8 percent
Amortization period	20 years

TABLE 2
Chlorination cost assumptions

Parameters	Costing Factors
Cost of chlorine	$0.33/kg ($300/ton)
Chlorine dose	2 mg/L
Contact time (when used)	20 min

and hospital care. The costs foregone were calculated as benefits because of installation of technology. The costs for each technology (filtration and chlorination) were calculated based on historical costs. The possible negative benefits resulting from formation of trihalomethanes caused by chlorination were not considered in this analysis. Costs and benefits were computed using 1907 as a base year.

Figures 3 and 4 show the costs and benefits resulting from filtration alone and in combination with chlorine, respectively. Because chlorination has always been combined with filtration in Cincinnati, it is not possible to analyze its benefits directly. A calculation was devised, however, to simulate the effect of chlorination alone. Those benefits associated with the decline in typhoid death and incidence rates, following introduction of chlorination, were reduced by 80 percent to reflect the reduced effectiveness of chlorination without filtration.[6] Figure 5 shows the impact of an 80 percent reduction in benefits to simulate the effect of chlorination alone. Assuming a 6 percent discount rate, Figures 3–5 all show that the benefits of chlorination and filtration, combined or alone, exceed the costs.

Perhaps the most impressive feature of these curves is that in no case does the cost curve turn upward in comparison to the benefit curve. Each technology pays for itself in a short time, establishing disinfection as a highly cost-effective practice. Within this mathematical framework cost assumptions can be made for chlorine dioxide, ozonation, and combined chlorine.

Disinfectant costs

The assumptions made for the cost analysis (1980) are given for each unit process and followed by a graphical comparison showing the influence of concentration on the cost of disinfection.[7] Both chlorine dioxide and combined chlorination are analyzed with and without the use of a contact basin. This approach allows for cost comparisons between those cases in which an existing disinfection process is simply being changed and those cases in which construction of a new facility is required. Table 1 contains the cost assumptions used in each of the calculations.

Chlorine. The design variables unique to the cost computations for chlorination are shown in Table 2. The data in Figures 6 and 7 show the total treatment costs for chlorination versus chlorine dosage for plants of several capacities, with and without contact basins. The data in Table 3 show O&M, capital, and total treatment costs for 38-ML/d (10-mgd) and 380-ML/d (100-mgd) plants operating at 70 percent capacity, with a chlorine dosage of 2 mg/L.

TABLE 3
Capital and operating costs for chlorination

Operating Parameters	Cost for Chlorination at 2-mg/L Dosage			
	38-ML/d (10-mgd) Plant Capacity		380-ML/d (100-mgd) Plant Capacity	
	¢/kL	¢/1000 gal	¢/kL	¢/1000 gal
Without contact basin				
O&M cost	0.2	0.6	0.1	0.3
Capital cost	0.1	0.2	<0.1	0.1
Total treatment cost	0.3	0.8	>0.1	0.4
With contact basin				
O&M cost	0.2	0.6	0.1	0.3
Capital cost	0.2	0.6	0.1	0.4
Total treatment cost	0.4	1.2	0.2	0.7

TABLE 4
Chlorine dioxide assumptions

Parameters	Costing Factor
Chlorine	$0.33/kg ($300/ton)
$NaClO_2$	$0.22/kg ($200/ton)
Chlorine dioxide dose	1 mg/L
Contact time (when used)	30 min

TABLE 5
Capital and operating costs for chlorine dioxide

Operating Parameters	Cost for Chlorine Dioxide at 1-mg/L Dosage			
	38-ML/d (10-mgd) Plant Capacity		380-ML/d (100-mgd) Plant Capacity	
	¢/kL	¢/1000 gal	¢/kL	¢/100/gal
Without contact chamber				
O&M cost	0.2	0.8	0.1	0.5
Capital cost	0.2	0.3	< 0.1	0.1
Total treatment cost	0.4	1.1	> 0.1	0.6
With contact chamber				
O&M cost	0.2	0.8	0.1	0.5
Capital cost	0.2	0.8	0.1	0.5
Total treatment cost	0.4	1.6	0.2	1.0

TABLE 6
Capital and operating costs for ozone

Operating Parameters	Cost of Ozone at 1-mg/L Dosage			
	38-ML/d (10-mgd) Plant Capacity		380-ML/d (100-mgd) Plant Capacity	
	¢/kL	¢/1000 gal	¢/kL	¢/1000 gal
O&M cost	0.2	0.7	0.1	0.4
Capital cost	0.4	1.5	0.3	0.9
Total treatment cost	0.6	2.2	0.4	1.3

TABLE 7
Cost assumptions for chloramination

Parameter	Costing Factors
Chlorine	$0.33/kg ($300/ton)
Ammonia	$0.22/kg ($200/ton)
Ratio of chlorine to ammonia	3:1
Chlorination dose	3 mg/L
Contact time	20 min

TABLE 8
Capital and operating costs for ammoniation

Operating Parameters	Cost of Ammoniation at 3-mg/L Dosage			
	38-ML/d (10-mgd) Plant Capacity		380-ML/d (100-mgd) Plant Capacity	
	¢/kL	¢/1000 gal	¢/kL	¢/1000 gal
Without contact basin				
O&M cost	0.5	1.8	0.3	1.3
Capital cost	0.2	0.6	0.1	0.2
Total treatment cost	0.7	2.4	0.4	1.5
With contact time				
O&M cost	0.5	1.8	0.3	1.2
Capital cost	0.2	0.9	0.1	0.5
Total treatment cost	0.7	2.7	0.4	1.7

Chlorine dioxide. Table 4 contains the cost assumptions for chlorine dioxide. To achieve equivalent disinfection results the chlorine dioxide dose is assumed to be half the chlorine dose. Thus 1 mg/L of chlorine dioxide was assumed to achieve disinfection results equivalent to those achieved by 2 mg/L of chlorine. The data in Figures 8 and 9 show the total treatment costs for various-sized systems using chlorine dioxide with and without contact basins. The data in Table 5 summarize O&M, capital, and total treatment costs for chlorine dioxide for 38-ML/d (10-mgd) and 380-ML/d (100-mgd) plants operating at an average capacity of 70 percent.

Ozonation. The data in Figure 10 show the cost of various ozone dosages at different-sized systems operating at 70 percent capacity, assuming a contact time of 10 min and ozonation dose of 1 mg/L. A dose of 1 mg/L is assumed to be equivalent in disinfecting capacity to 2 mg/L chlorine. Table 6 shows O&M, capital, and total treatment costs based on these assumptions.

Chloramination (combined chlorine). Combining ammonia with chlorine to form chloramines has been termed the chloramine process, chloramination, and combined residual chlorination. The design variables assumed for chloramination are shown in Table 7.

The data in Figures 11 and 12 show the total treatment costs for chloramines at various dosages for various-sized plants with and without contact basins. Table 8 contains O&M, capital, and total treatment costs for 38-ML/d (10-mgd) and 380-ML/d (100-mgd) plants at 3-mg/L dose of combined chlorine for plants operating at an average capacity of 70 percent.

Comparison of processes

The costs of the various disinfectants can be compared by examining Table 9, which summarizes their costs at presumed equivalent dosages. As can be seen in Figures 6–14, the marginal cost for an additional milligram per litre of chlorine is lower than for the other disinfectants.

Energy utilization

A subject of current concern is the energy costs associated with various unit processes. To provide insight into this issue, chlorination and ozonation were compared as shown in Table 10, which gives the energy usage for chlorination at various dosage rates, and Table 11, which gives energy usage rates for ozonation.

Chlorination and ozonation represent the extremes of energy usage for disinfection. As can be seen from Tables 10 and 11, because of economies of scale, unit energy cost decreases with increasing plant size. Table 12 compares energy usage for chlorination and ozona-

TABLE 9
Comparative costs

Process	Concentration mg/L	Operating Costs for Plant Capacity of 38 ML/d (10 mgd)–¢/kL			Operating Costs for Plant Capacity of 380 ML/d (100 mgd)–¢/kL		
		O&M	Capital	Total	O&M	Capital	Total
Chlorination							
Without contactor	2	0.2	0.1	0.3	0.1	< 0.1	> 0.4
With contactor	2	0.2	0.2	0.4	0.1	0.1	0.2
Chlorine Dioxide							
Without contactor	1	0.2	0.2	0.4	0.1	< 0.1	> 0.1
With contactor	1	0.2	0.2	0.4	0.1	0.1	0.2
Ozone	1	0.2	0.2	0.4	0.1	0.1	0.2
Ammoniation							
Without contactor	3	0.5	0.2	0.7	0.3	0.1	0.4
With contactor	3	0.5	0.2	0.7	0.3	0.1	0.4

TABLE 10
Energy usage for 2-mg/L chlorine concentration

Design Dosage		Actual Dosage		Energy Cost		Energy Ratio	
kg/d	lb/d	kg/d	lb/d	$/kg	$/lb	kWh/kg	kWh/lb
7.6	16.7	5.3	11.7	0.221	0.100	5.50	2.49
37.9	83.5	26.5	58.5	0.075	0.034	1.88	0.85
75.7	167	53.1	117	0.058	0.026	1.41	0.64
757.3	1670	530.6	1170	0.035	0.016	0.89	0.40
1136.0	2505	795.9	1755	0.031	0.014	0.80	0.36

TABLE 11
Energy usage for 1-mg/L ozone concentration

Design Dosage		Actual Dosage		Energy Cost		Energy Ratio	
kg/d	lb/d	kg/d	lb/d	$/kg	$/lb	kWh/kg	kWh/lb
3.8	8.4	2.6	5.8	1.722	0.779	43.05	19.48
19.0	41.8	13.3	29.3	1.006	0.455	25.15	11.38
37.9	83.5	26.5	58.5	0.902	0.408	22.56	10.21
378.7	835	265.3	585	0.738	0.334	18.48	8.36
568.0	1252.5	397.9	877.5	0.703	0.318	17.56	7.96

TABLE 12
Comparative energy usage of processes at 37.9 kg/d (83.5 lb/d)

Disinfection Process	Dosage kg/d	Energy Use kWh/lb
Chlorination	1.88	0.85
Ozone	22.56	10.21

tion at a common usage rate, indicating that for similar dosage levels chlorination is by far the less energy intensive of the two disinfectants.

Comparison of benefits of alternative disinfectants

A useful way to compare each of the primary disinfectants would be to evaluate them on a cost-benefit basis. When chlorine, ozone, and chlorine dioxide are put on the same cost-benefit basis, all three show a positive net benefit (Figure 15).

Although chlorination is the most cost-effective process, this analysis shows that all three disenfectants have a favorable cost-benefit relationship.

Summary and conclusions

Discovery of the formation of chloroform during chlorination and the subsequent trihalomethane regulations have caused an intensive examination of disinfection practices. The fact remains that disinfection and the combination of disinfection and filtration are highly cost-effective preventive public health practices. When various disinfectants are compared on the basis of dosage and energy consumption, chlorine is probably the cheapest disinfectant. In terms of incremental dosage, chlorine has the lowest marginal cost per unit increase in concentration. The costs of other disinfectants, however, are only slightly higher than that of chlorine, and disinfection on any basis shows a favorable cost-benefit relationship.

Acknowledgments

The author acknowledges the assistance of Paul Dorsey, Mike Laugle, James Goodrich, and Cheryl Stafford in the preparation of this manuscript.

References

1. *Fed. Reg.*, 44:231:68624 (Nov. 29, 1979); 45:49, 15542 (Mar. 11, 1980).
2. SYMONS, J.M. Utilization of Various Treatment Unit Processes and Treatment Modifications for Trihalomethane Control. Proc. Control of Organic Chemical Contaminants in Drinking Water. US EPA, Washington, D. C. (in press).
3. Annual Reports. Cincinnati Health Department (1902–1928).
4. Annual Reports. City of Cincinnati and Cincinnati Water Works (1909).
5. DUBLIN, L.I. & LOTKA, A.J. *The Money Value of a Man*. The Ronald Press Co., New York (1946).
6. FAIR, G.M. & GEYER, J.C. *Elements of Water Supply and Waste-Water Disposal*, John Wiley and Sons, Inc., New York (1957).
7. CLARK, R.M. & DORSEY, P. The Cost of Compliance: An EPA Estimate for Organics Control. *Jour. AWWA*, 72:8:450 (Aug. 1980).

Robert M. Clark is chief, economic analysis, municipal environmental research laboratory, office of research and development, US EPA, Cincinnati, Ohio 45268.

Printed in U.S.A.